MODELING OF PARTIAL DISCHARGE IN TRANSFORMER WINDINGS AND ITS DETECTION

A Thesis submitted in partial fulfilment

Of the requirements for the Award of degree of

Bachelor of Technology

In

Electrical Engineering

By

SAPEETHAA THAMPITHURAI

ROLL NO -110EE0646

December, 2014

Department of Electrical Engineering

National Institute of Technology

Rourkela -769008

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Under guidance of

Dr.S.KARMAKAR

Department of Electrical Engineering

National Institute of Technology

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National Institute of Technology, Rourkela

CERTIFICATE

This is to certify that the Project Report entitled **"Modeling of Partial discharge in Transformer Windings and its detection"** submitted **by Miss. Sapeethaa Thampithurai** in Partial fulfilment of the Requirements for of the requirements for the award of Bachelor of Technology Degree in **Electrical Engineering** at National Institute of Technology, Rourkela (Deemed University) is an authentic work Carried out by him under my supervision and guidance.

To the best of my Knowledge the matter embodied in this Project Report has not been submitted to any other University for the award of any Degree or Diploma.

Date:

Dr.S.Karmakar
Department Of Electrical Engineering
NIT Rourkela.

AKNOWLEDGEMENT

I would like to express my gratitude to my guide **Dr. S. KARMAKAR** Professor of Electrical Department for his constant support, advice for the betterment of my research project work and proper mentoring throughout my studies. His technical advice has played a key role in the completion of the stipulated time. His teaching ability, depth of knowledge and a perfect insight into the problems will always be an inspiration to me and all his students.

Finally, I would like to express my heartiest thanks to my parents and Family to being with me when facing difficulties.

Place: National Institute of Technology Rourkela.

Date: Sapeethaa Thampithurai

(110EE0646)

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ABSTRACT

In the power system network, power transformer is plays an important role for maintaining the constant system operating voltage throughout its long service life. Most of the high voltages transformers are manufacture with different kind of solid insulation (i.e., paper, mica, ceramic insulator, and spacer etc.) to withstand such high voltage stress. Therefore, insulation condition monitoring of such transformers are the utmost important routine work for every power engineers to increase its reliability. It is studied that, partial discharge (PD) is one of the causes of insulation failure in high voltage power transformer winding as it is suffers high voltage stress throughout the service period. Therefore, it is very important to early detection of PD inside the transformers for reliable operation of the high voltage equipment and avoids massive failure in the power system network. In this study, a simulation model is developed for disc type power transformer winding to simulate the PD activity inside the transformer using the MATLAB Simulink environment.

LIST OF ABBREVIATION

IEC standard	International Electro Techno Commission
PD	Partial Discharge
HV	High Voltage
UHV	Ultra High Voltage
AE	Acoustic emission
MV	Mega Volt
MI	Measurement of Instrumentation

LIST OF SYMBOLS

Symbol	Name of the symbol
C_a	Capacitance of air
C_s	Capacitance of solid
E_a	Electrical Field of air
E_s	Electrical field of solid
L_i	Leakage inductance
R_i	Loss due to insulation between adjacent winding section
C_{si}	Coil to coil capacitance
C_{gi}	Coil to ground capacitance
C_{gp}	Capacitance of the region where the discharge takes place
C_b	Capacitance of the region
C_a	Capacitance of the rest region in the dielectric
R_d	Resistance of the detection circuit
L_d	Inductance of the detection circuit
C_d	Capacitance of the detection circuit

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Chapter - 01

INTRODUCTION

1.1 Introduction

Partial discharge (PD) monitoring in Power Transformer is a useful technique to evaluate the condition of insulation system. PD signals are linked to the transformer insulation system High levels of these signals may lead to broken of the insulation. In fact, PD analyses in power transformers has been widely applied for detecting and quantifying premature damage in insulation systems, therefore detection and location plays an important role. However, detection and location of PD in power transformer has been a complex task, since its random occurrence may produce a wide frequency spectrum.

Several electrical methods for PD location in Transformer winding have been developed in previous studies. For instance, a method in frequency domain is proposed for PD location in Transformer windings using correlation techniques [1]. Applied wavelet packages for PD location, where the high frequency information is used to estimate the PD position, particularly detail coefficients at the first decomposition level are analyzed. Transfer function method is applied in, where the PD location is determined by series resonance frequencies, in the same way, transfer function per section have been applied to determine the PD position along the winding transformer.

This project proposes the method for PD location along the transformer windings and between winding sections. PD signals are proceed using the transformer, where the Laplace function is taken in the transformer windings and simulated with PD signal. In this work to measure the PD in transformer winding, have to find the parameters.

1.2 MOTIVATION & OBJECTIVE OF THE THESIS

1.2.1 MOTIVATION

The appearance of PDs is a problem for insulation failure of power transformer winding used in power plant. It is seen that most of the transformer winding are manufactured with great care so that no impurity is added in the winding insulation. But some small amount of impurity is always present during it manufacturing process. The impurities are in the form of solid, liquid or gas. During the manufacturing process of such winding insulator the impurity is present in the form of air bubble which creates a weak zone inside the winding. Most of the failure of such insulation occurs due to presence of PD at the weak zones with high voltage stress in the transformer winding. Therefore, detection and the measurement of such PD s are very much important task to avoid the catastrophic failure of the power transformer as well as reliable operation of the transformer throughout its service period.

1.2.2 OBJECTIVES OF THE THESIS

Complete freedom of discharges in high voltage equipment is hardly ever attained and a compromise solution in which the level is below a value measurable with an adopted technique is usually accepted. The significance of PD on the life of insulation has long recognized and many workers have attempted to measure some aspects of discharges. The various discharge measurement techniques have recently been reviewed by Krueger and Mason [2]. The detection of discharges. These exchanges are manifested as:

(1) Electrical Impulses
(2) Dielectric losses
(3) E.M radiation (light)
(4) Sound (noise)
(5) Increased gas pressure,
(6) Chemical transformations

The parameters which must be determined include:

(1) Detection, determination of presence of discharges and the voltage at which they appear.
(2) Location ,determinations of the site of discharge
(3) Evaluation, magnitude of discharges and detoriation limit.

The main objectives of the Thesis

- To observe the PD occurrences in transformer winding.
- Finding the parameters of the PD observed in the transformer winding.
- Simulation of the PD in transformer winding by using MATLAB software.

1.4 ORGANIZATION OF THE THESIS

This Thesis consists five (5) chapters .

CHAPTER - 01 This chapter consist the introduction, literature view, motivation and objective of the thesis. It is also includes the organization of the thesis.

CHAPTER - 02 This chapter includes the background literature view of the Partial discharge in transformer winding. Also a brief discussion about the partial discharge. It consist the equivalent circuit of the transformer winding.

CHAPTER - 03 It consists the methodology used for determining the parameters of the transformer winding circuit by using MATLAB. To study about the Partial discharge artificial void invented and observed the PD signal through rise time and fall time. And calculated the parameters value from standard equations.

CHAPTER - 04 In this chapter observed the simulation output pulse from the LTI viewer and FFT viewer. Also discussed about the output signal of the PD mearsument. It includes so many figures on PD signal of the transformer winding with different voltages and comparing with these waves calculating the rise time and fall time of the generated pulse. The effect of the different output was discussed with the absolute reason, and with the help of the Simulink values.

CHAPTER - 05 Finally, in this last chapter it includes conclusion of this Thesis work and final results with the reference.

Background and Literature Review

Literature Review

Chapter – 02
LITERATURE REVIEW

2.1 LITERATURE REVIEW

In the last century, when the high voltage technology was introduced for electrical power generation and transmission system, Partial discharges have already has been recognized as a harmful source for detection, measurement and behavior study of partial discharge inside the transformer winding. The authors Z.D.Wang, P.A.Crossley and K.J. Cornick has discussed about the detection and measurement of PD propagation in power transformer. Also about the general simulation model of the Transformer windings, method of Calculation of the Transformer winding parameters. The Researcher Mehdi Nafar, Taher Niknam and Amir Hossein Gheisari have done a work on the locating partial discharge in the Power Transformer using correlation coefficient. They have used the disk winding for partial discharge simulation for HV transformer.Peter Werle, Hossein Borsi, Ernst Gockenbach, M.S. AbdRahman, L.Hao, P.Rapisardo, P.L.Lewin and Asghar Akbari all have given a proposal on the PD simulation for a transformer winding by using a model based on geometrical dimensions. And they have done the Experiment work also. At last they have compared the results which they got from the simulation and pratical.so they analyzed about their outputs [7]

2.2 Partial Discharges

Partial discharge is defined as localized discharge process in which the distance between two electrodes is only partially bridged i.e. the insulation between the electrodes is partially punctured. Partial discharges may originate directly at one of the electrodes or occur in cavity in the di-electric. Some of the typical partial discharges are [5], [6]:

(1) Corona or gas discharge
These occur due to non-uniform field on sharp edges of the conductor subjected to high voltage especially when the insulation provided is air or gas or liquid.

(2) Surface discharge and discharges in laminated materials
The materials on the interfaces of different dielectric material such as gas/solid interface as gets over stressed εr times the stress on the solid material and ionization of gas results.

(3) Cavity discharge
When cavities are formed in solid or liquid insulating materials the gas in the cavity is over stressed and discharges are formed

(4) Treeing channels

High intensity fields are produced in an insulating material at its sharp edges and its detoriates the insulating material. The endures partial discharges consequently produced are known as Treeing channels.

2.3 External Partial Discharge & Internal Partial discharge

External Partial discharge is the process which occurs external to the equipment e.g. on overhead lines, on armature etc.

Internal Partial discharge is a process of electrical discharge which occurs inside a closed system (discharge in voids, treeing etc.) This kind of classification is essential for the PD measuring system as external discharges can be nicely distinguished from internal discharges. Partial discharge measurement have been used to access the life expectancy of insulating materials. Even though there is no well-defined relationship, yet it gives sufficient idea of the insulating properties of the material. Partial discharges on insulation can be measured not only by electrical methods but by optical, acoustic and chemical methods also. The measuring principles are based on the energy conversion process associated with electrical discharges such as emission of electromagnetic waves, light, noise or formation of chemical compounds. The oldest and simplest but less sensitive is the method of listening to hissing sound coming out of partial discharge. A high value of loss factor tan δ is an indication of occurrence of partial discharge in the material. This is also not a reliable measurement as the additional losses generated due to application of high voltage are localized and can be very small in comparison to the volume losses resulting from polarization process. Optical methods are used only for those materials which are transparent and thus not applicable for all materials. Acoustic detection methods using ultrasonic transducers have, however, been used with some success. The most modern and the most accurate methods are the electrical methods. The main objective here is to separate impulse currents associated with PD from any other phenomenon [4].

2.4 Partial discharge in solid insulation

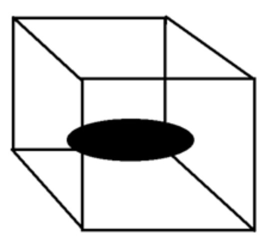

Figure 2.1 model of cubic insulator

If there are any partial discharges in a dielectric material, these can be measured only across its terminal. Figure 2.1 shows a gas filled void is present. The Partial discharge in the void is ε_r times the stress in the rest of the material where εr is the relative permittivity of the material. Due to geometry of the material, various capacitances are formed as shown in Figure 2.2. Flux lines starting from electrode and terminating at the void will form one capacitance C_{b1} and similarly C_{b2} between electrode B and the cavity. C_c is the capacitance of the void. Similarly C_{a1} and C_{a2} are the capacitance of healthy portions of the dielectric on the two sides of the void [3].

2.5 Partial discharge measurements

A number of discharge detection schemes and partial discharge measurement methods have been invented since the importance of PD was realized early in the last century. Partial discharge currents tend to be of short duration and have risen times in the nanosecond realm. On an oscilloscope. The discharges appear as evenly spaced burst events that occur at the peak of the sine wave. Random events are arcing or sparking. It consist Testing object and Measurement instrument. Testing object consists capacitance C_3 (C_c), C_4 (C_a) and C_5 (C_b). Pd in Void will be measuring by V_t. MI is the measurement instrument which used to distinguish the observed electrical discharges from the test object.

HV Source Voltage Transformer - V

Filter unit - R

High voltage measuring capacitor - C_1

Coupling capacitor - C_2

Void model voltage - Vt

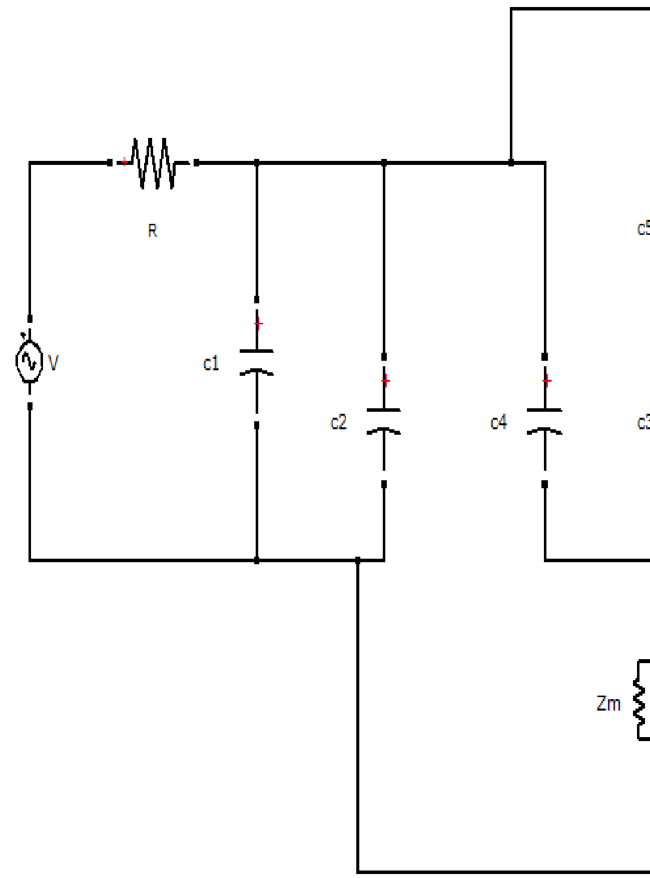

Figure 2.2 Equivalent circuit for PD measuring

Figure 2.1 shows the sample model of cubic insulator (3 cm × 3 cm × 3cm) with the cylindrical void middle

It consists: -

$$C = \frac{Q}{V}$$

$$C = \frac{\varepsilon A}{d}$$

$$\frac{1}{C_{\text{eq}}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}$$

$$C_{\text{eq}} = C_1 + C_2 + \cdots + C_n$$

By using these equations calculated the values of L, R, C, ω, σ, ρ, C_1, C_2, C_3, C_4, C_5, & Q

Taking dielectric portion as a cube and void inside the cube is cylindrical void.

C_4 = 20.257 p C_5 = 73.522 pF

C_3 = 58.39 pF C_1 = 200 pF C_2 = 1000

Length of the cube is 3 cm × 3 cm × 3 cm

Void length is 1.5 cm and Void radius is 2 mm

Volume of the cube – $V = \pi r^2$h

= 0.6π cm^3

$Q = CV$

In test object R = 50 Ω

L = 0.63 mH

C = 0.47 μF

And the filter unit resistance is 0.5 Ω

MODELING OF PARTIAL DISCHARGE IN TRANSFORMER WINDING

Methodology used for determining

PD Equivalent circuit

Chapter – 03

PD IN TRANSFORMER WINDING

3.1 Partial discharge in transformer winding

Considering the number of failures in high voltage power transformer caused by problems in bushing and winding insulation, it is important to study means for diagnosing incipient failures, to avoid long un availability periods and its consequences. The Aim of this project is to study about the modeling of partial discharge in transformer windings and its detection inside the transformer. The methodology is based on the measurement of partial discharges from the Transformer winding. Here transformer winding designed with the help of the series capacitors and grounding capacitors and tested the partial discharge in different windings. And then observe the pulses

Considering the mathematical model of a single layer transformer winding shown in figure 3.1 high frequencies in the measurement are due to the capacitance present between transformer windings and earthed parts ,with in each winding, between discs, turns and layers, and between individual coils. This capacitance the voltage distribution of steep front over voltages within the Transformer will not be uniform [3]. A section of the model two of its element, each of its length dx, the inductance of each element is denoted by L [H/m], its shunt capacitance by Cg [F/m], and its series capacitance by Cs [F/m] [2].

Figure 3.2 shows the equivalent circuit to measure the PD in windings. In different winding taps by connecting the testing point observation will be taking. The PD pulse movement will be differ in each tap with respect to their distance from the source.

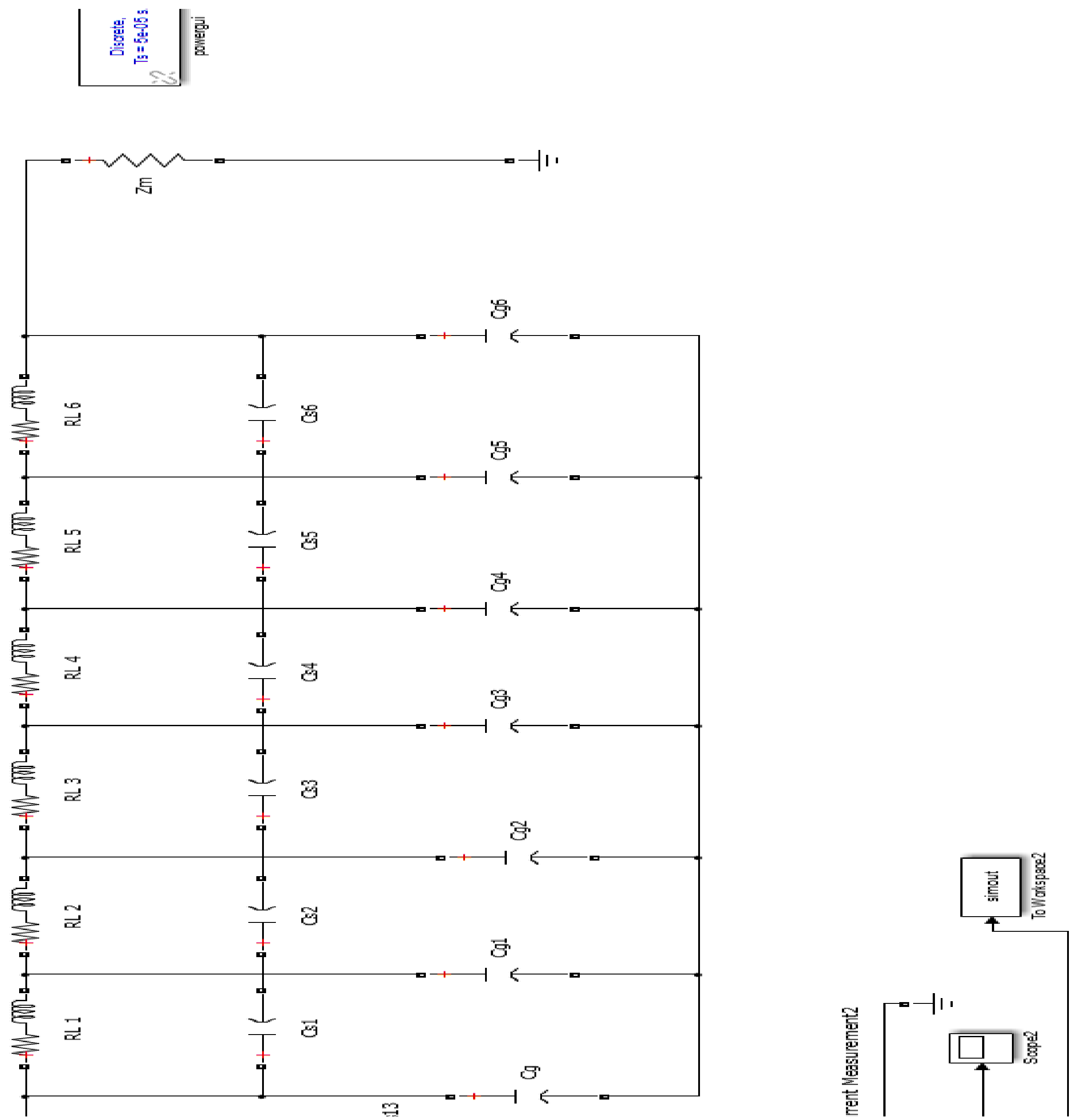

Figure 3.1 Mathematical model of a transformer winding at high frequencies

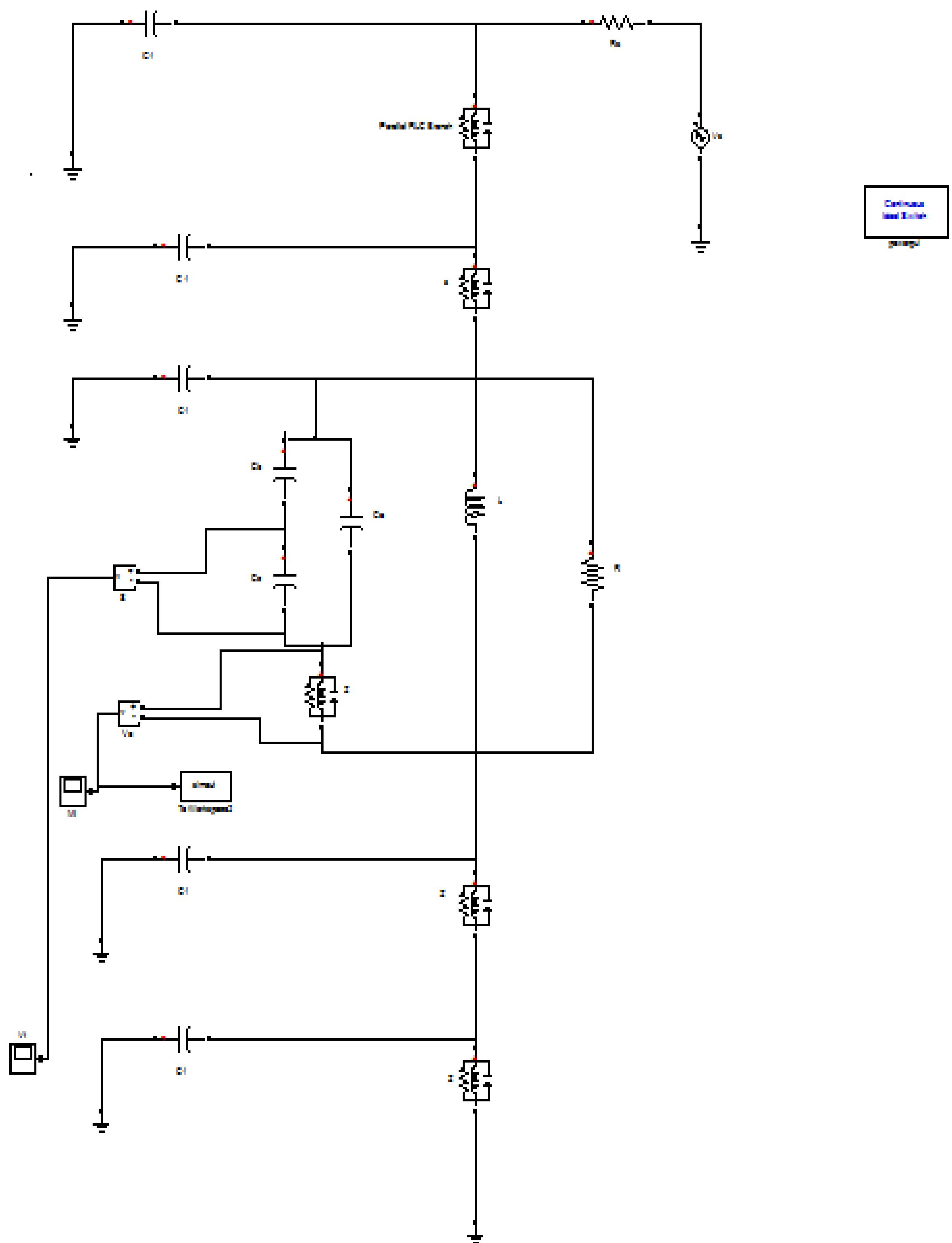

Figure 3.2. Equivalent circuit for testing PD in transformer winding

3.2 Equations to calculate the Parameters

$$Z] = Rs\,[In] + j2\Pi f\,[L]$$

$$[Y] = [G] + j2\Pi f\,[C]$$

Where Rs = Resistance

[L] = inductance matrix

[C] = capacitance matrix

[G] = conductance matrix

[In] = Unit matrix and f is the frequency

The inductance is assumed that the magnetic flux penetration into the laminated iron core is negligible at frequencies above 1MHz.The inductance is calculated by assuming the winding consists of loss-less multi conductor transmission lines surrounded by homogeneous insulator.

Hence

$$[L][C] = [C][L] = \mu\mathcal{E}\,[In]$$

Here μ and $\mathcal{E}$ are the permeability and permittivity of the insulation

$$[Ln] = \frac{\mathcal{E}_r}{c^2}\,[Cn]^{-1}$$

Here Cn = capacitance without insulation

$\mathcal{E}_r$ = relative permittivity of insulation

c = velocity of light in free space

At high frequency the flux internal to the conductor also creates an inductance

$$L_i = \frac{Rs}{2\Pi f}$$

Here where Rs is the resistance due to skin effect. And f is the frequency. The total inductance is given by

$$[L] = [Ln] + [Li][In]$$

So now the resistance calculation, the skin effect at high frequencies is taken into account. The resistance per unit length of conductor is given by

$$Rs = \frac{1}{2(d1+d2)}\sqrt{\frac{\Pi\mu f}{\sigma}}$$

Where d1 and d2 = cross sectional dimensions of rectangular conductor, μ = permeability of conductor,

σ =conductivity and f = frequency.

Conductance G is due to the capacitive loss in the insulation. It depends upon the frequency f, the capacitance C and the dissipation factor tan δ [7], [8].

$$[G] -2\Pi f\ [C] \tan\delta$$

The $\quad \text{Tan}\ \delta = 0.07(1 - \frac{6}{7}e^{-(0.308f*10\wedge-6)})$

Hence $[G] = 0.04f[C]\ (1 - \frac{6}{7}e^{-(0.308f*10\wedge-6)})$

For Figure 3.1 PD location using the series resonant frequencies the equation is given as:

$$xo = 1 - \frac{n}{2f}\sqrt{\frac{1-4\pi^2 f^2 LCs}{LCg}}$$

Where:

xo - Location PD along the winding height (p.u);

n - Order of series resonant frequency considered;

f - Value of the series resonant frequency [Hz].

SIMULATION RESULTS AND DISCUSSION

PD Mechanism

Chapter – 04

SIMULATION AND DISCUSSION

4.1 PD Mechanism

A number of discharge detection schemes and partial discharge measurement methods have been conceived subsequently the status of PD was realized early in the last century. Partial discharge currents have a tendency to be of short duration and have risen times in the Nano seconds [8]. On an oscilloscope, the liberations perform as uniformly spaced surge events that occur at the peak of the sine wave. The usual way of measuring partial discharge is in Pico coulombs. An instinctive analysis of the reflect grams collected during the partial discharge measurement – using a method referred to as time domain reflectrometry (TDR) – allows the location of insulation irregularities [9]. A phase-related representation of the partial discharges provides additional information, useful for the evaluation of the method below.

Table 2 : Applied voltage with different phase angle

Applied voltage (kV)	Phase angle (ϕ)
5	275°
15	315°
20	45°
50	0°
70	120°

For specified applied voltage and particular phase angle have observed the output PD signal through test object (Figure 4.2.1,4.3.1,4.4.1,4.5.1) and from the MI, the scope which gives the simulated signal of measuring part (Figure 4.2.2,4.3.2,4.4.2,4.5.2)of extracted frequency plot.

From here studied about the PD simulation output signals in a different types by giving some sample voltages with different phase angles, and observed the characteristics of the output signal.

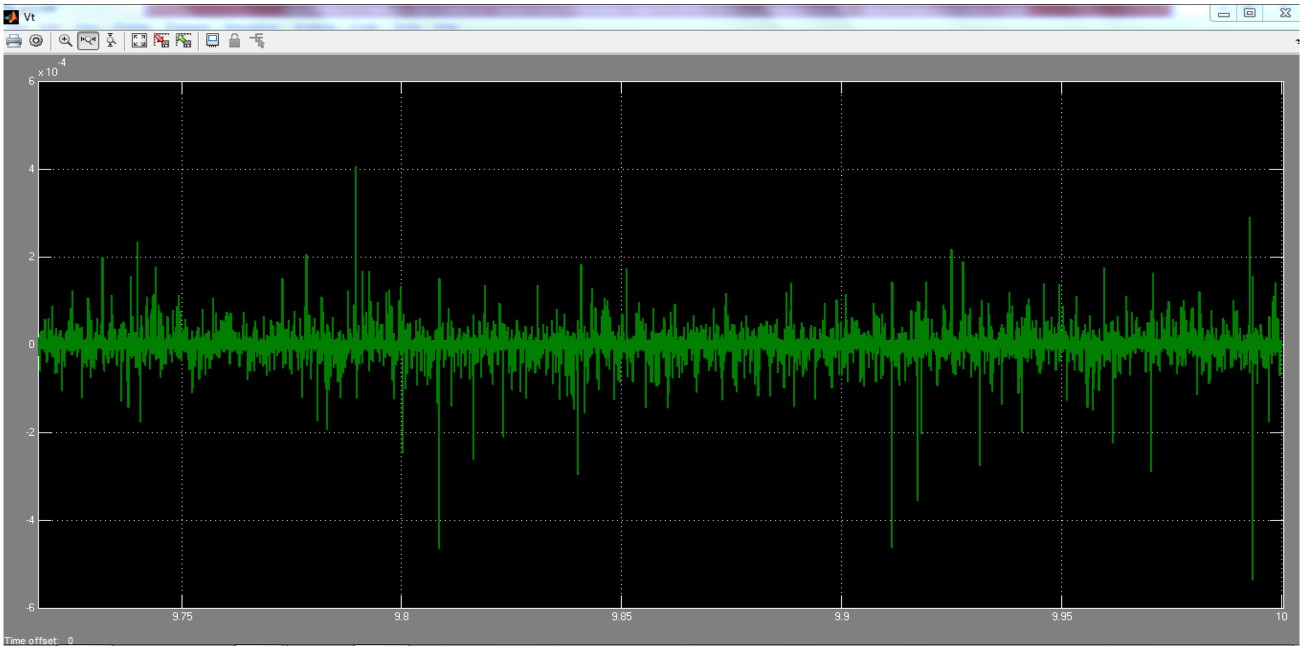

Figure 4.1.1. Snapshot of the output of the PD signal from test object for 5 kV source

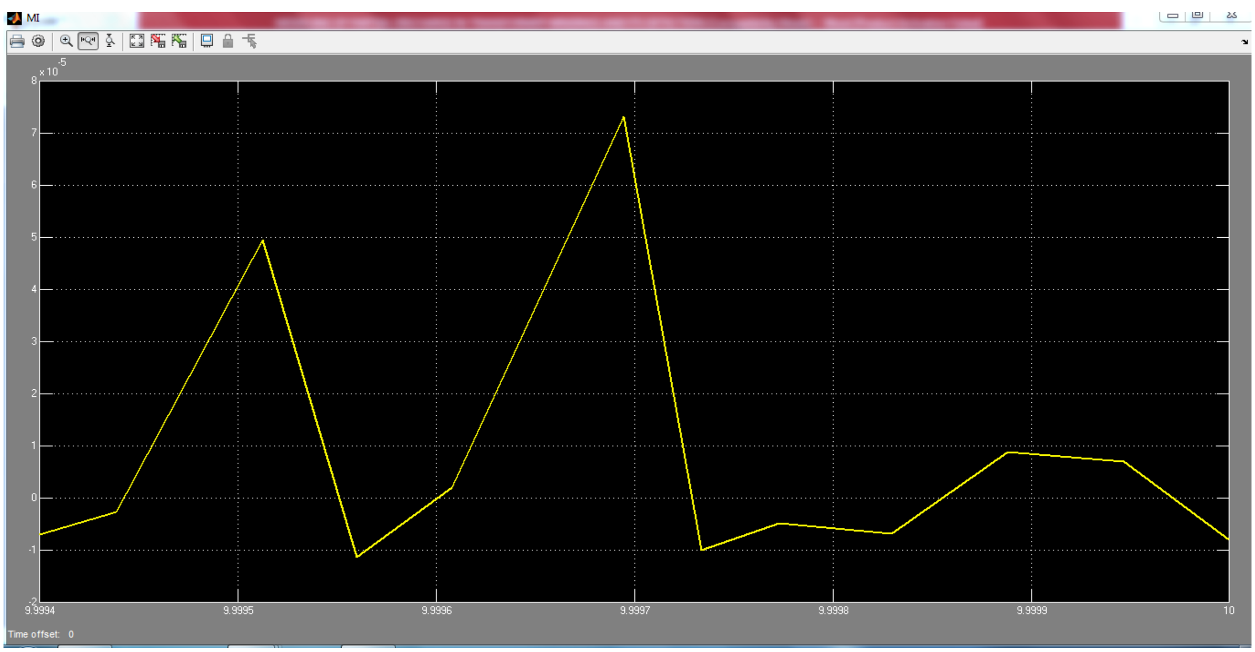

Figure 4.1.2. Snapshot of the output of the PD signal from MI for 5 kV source

The Figure 4.1.1 is the PD output signal of the test object with the 5 kV applied voltage, and Figure 4.1.2 is the output signal from MI for 5 kV Source voltage .Here can see the rise time and fall times clearly.

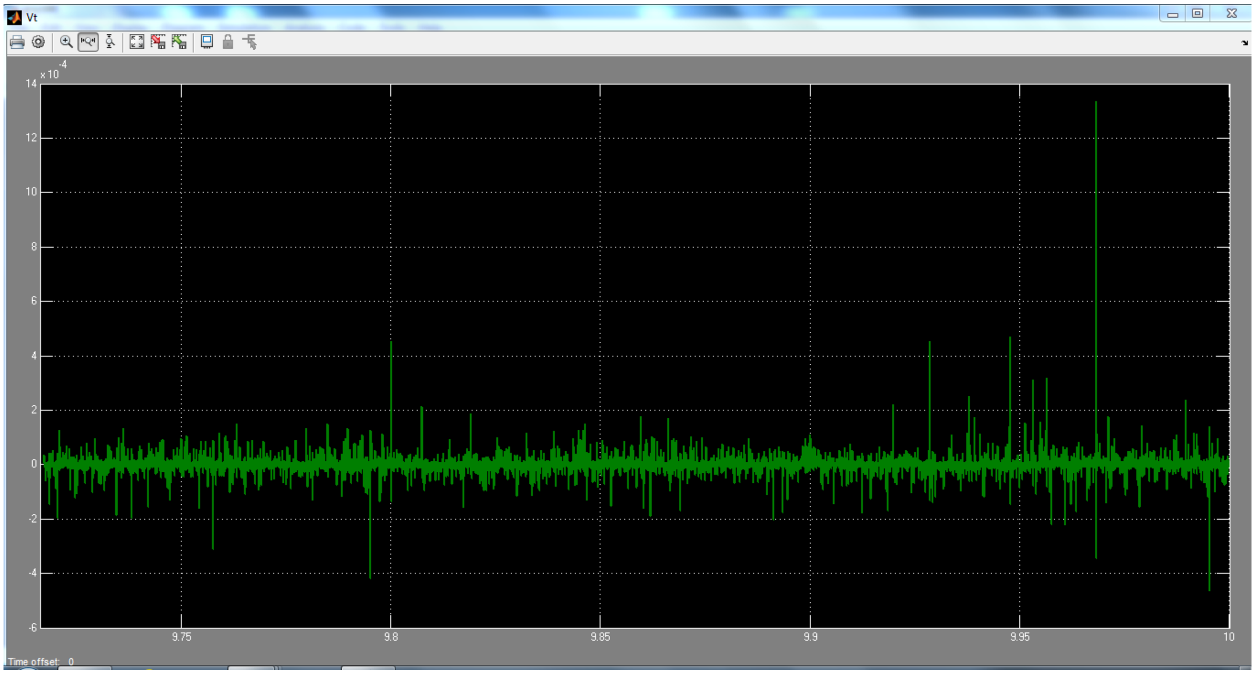

Figure 4.2.1. Snapshot of the output of the PD signal from test object for 15 kV source

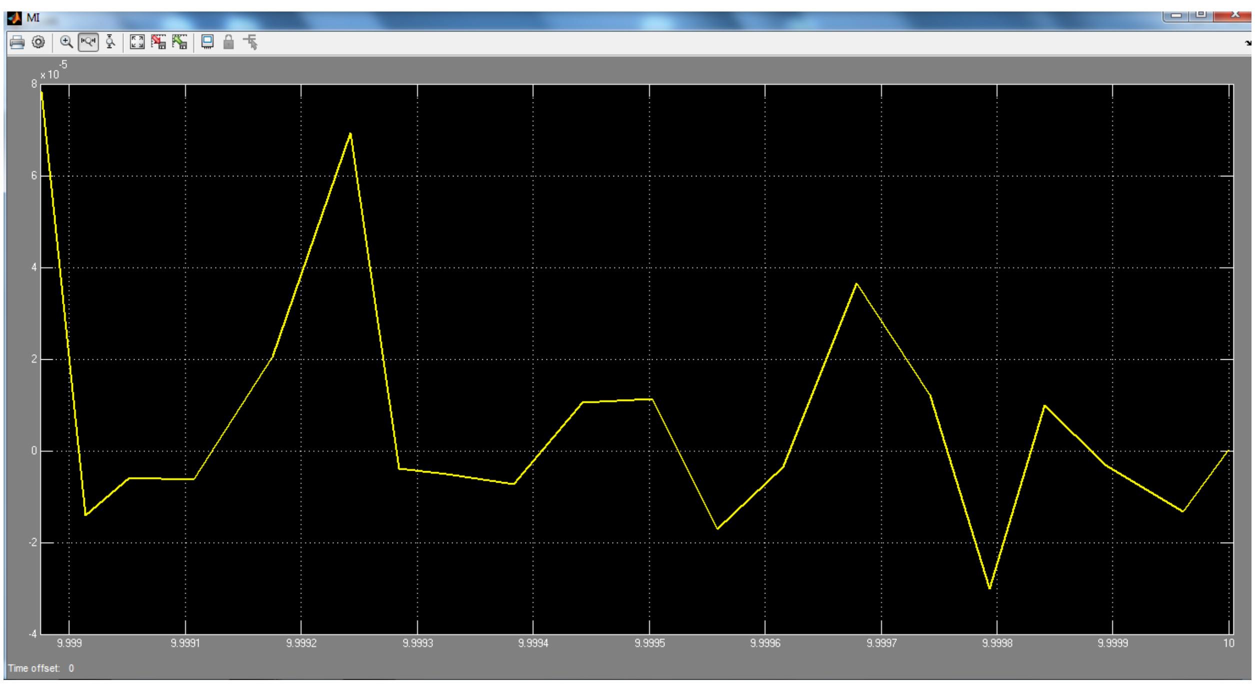

Figure 4.2.1 Snapshot of the output of the PD signal from MI for 15 kV source

The Figure 4.2.1 is the PD output signal of the test object with the 15 kV applied voltage, and Figure 4.2.2 is the output signal from MI for 15 kV Source voltage.

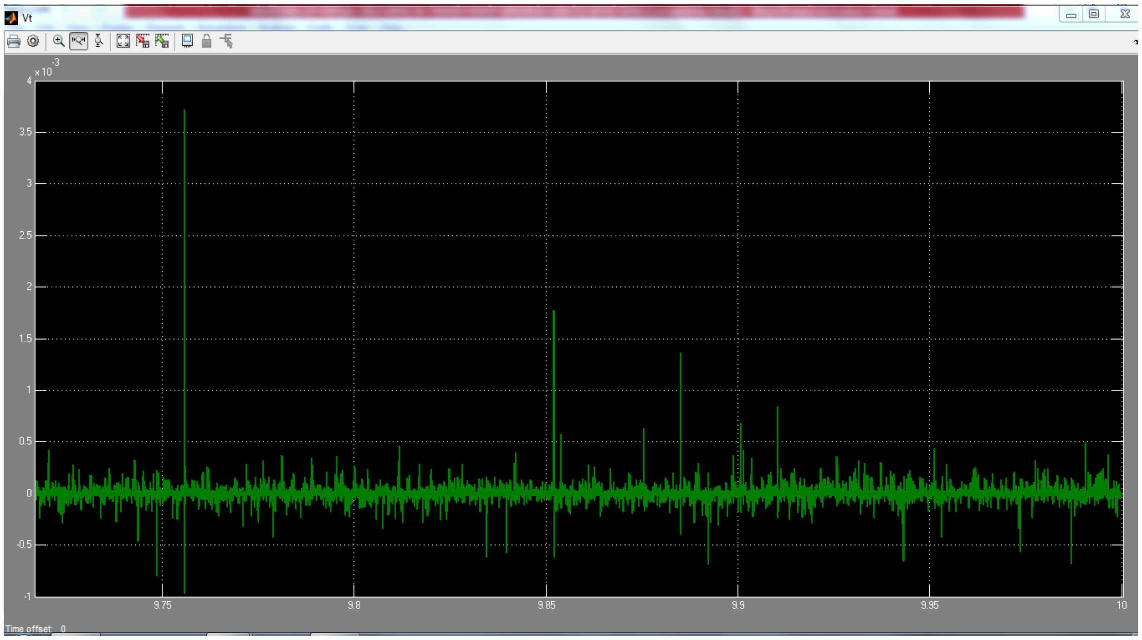

Figure 4.3.1 Snapshot of the output of the PD signal from test object for 20 kV source

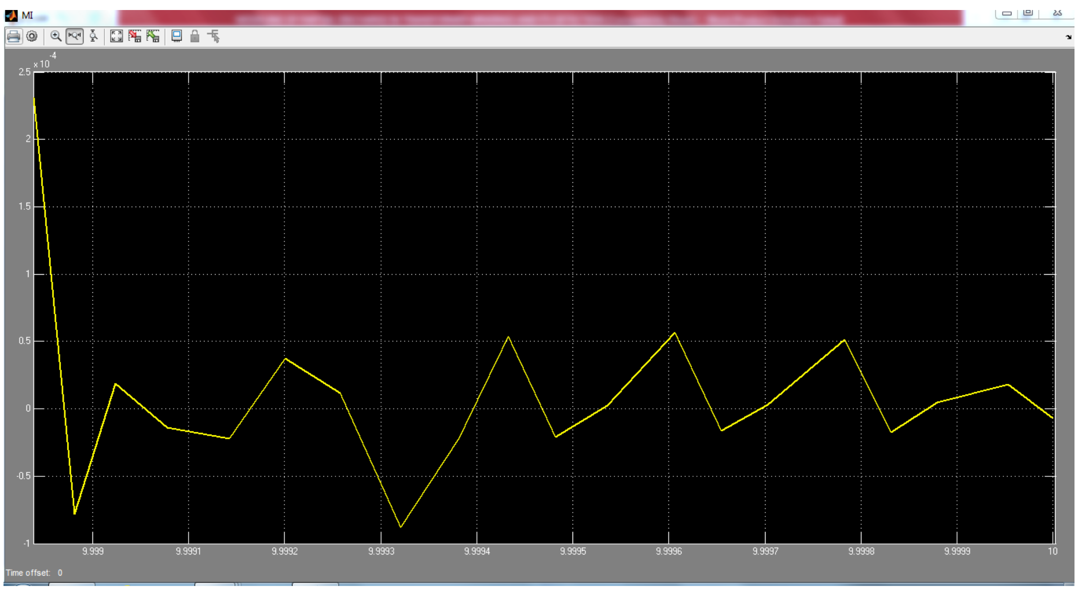

Figure 4.3.2 Snapshot of the output of the PD signal from MI for 20 kV source

The Figure 4.3.1 is the PD output signal of the test object with the 20 kV applied voltage, and Figure 4.3.2 is the output signal from MI for 20 kV Source voltage.

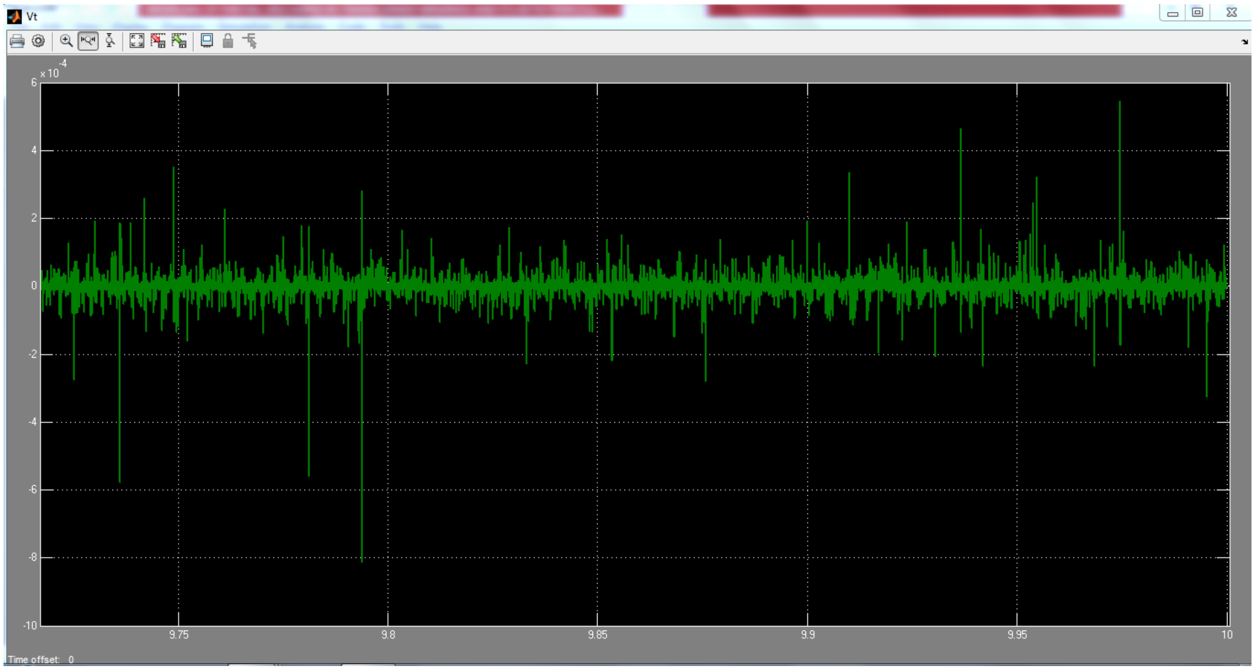

Figure 4.4.1 Snapshot of the output of the PD signal from test object for 50 kV source

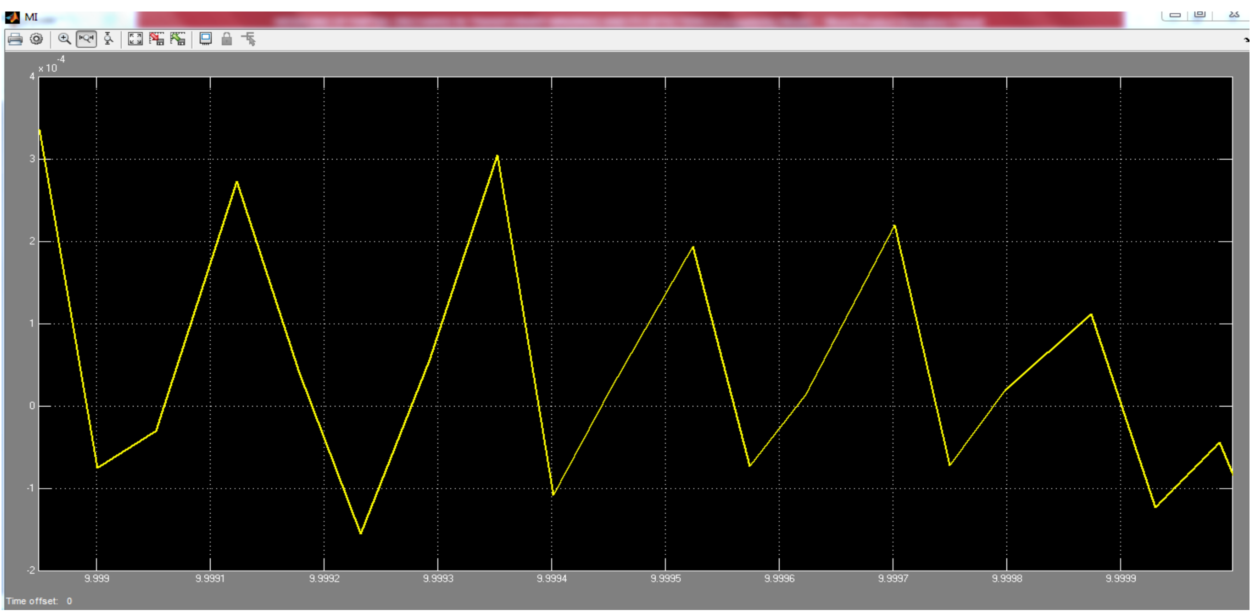

Figure 4.4.2 Snapshot of the output of the PD signal from MI for 50 kV source

The Figure 4.4.1 is the PD output signal of the test object with the 50 kV applied voltage, and Figure 4.4.2 is the output signal from MI for 50 kV Source voltage.

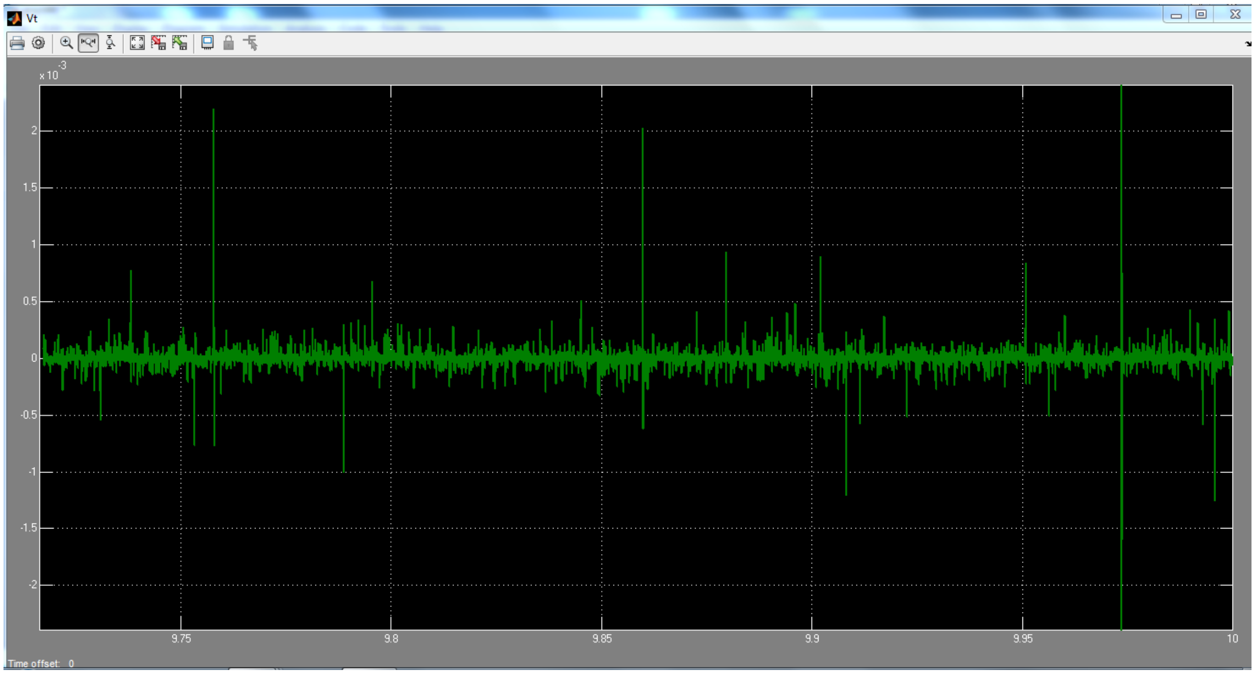

Figure 4.5.1 Snapshot of the output of the PD signal from test object for 70 kV source

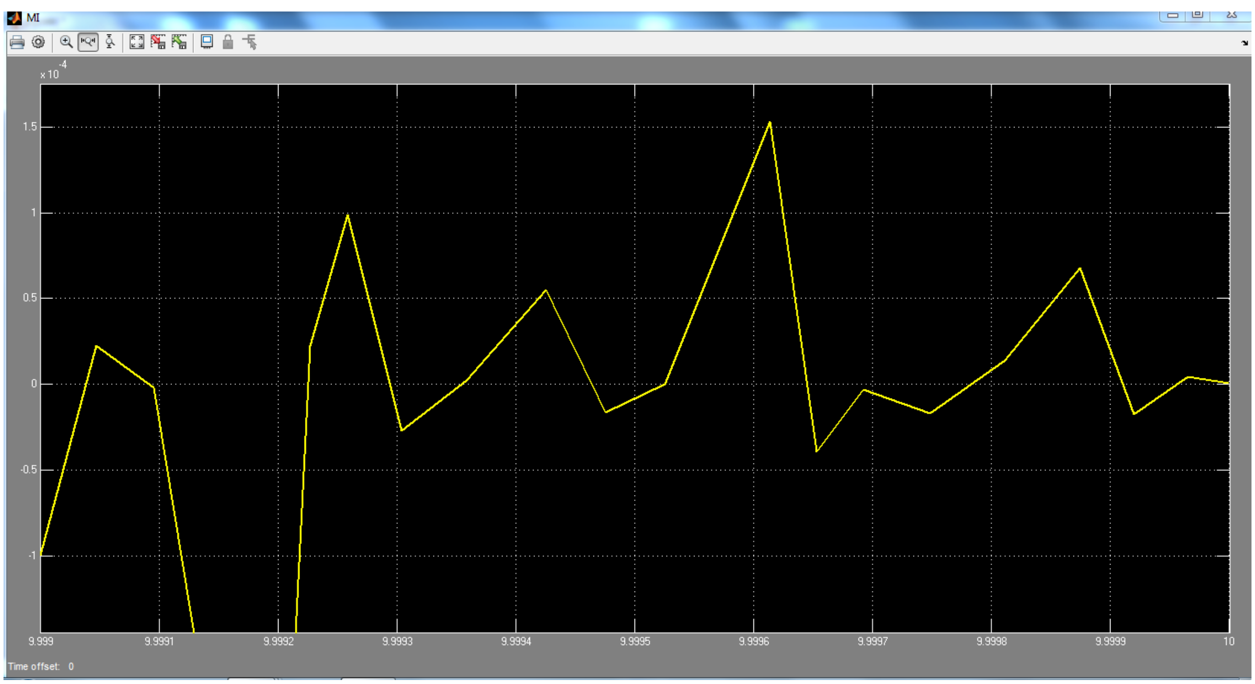

Figure 4.5.2 Snapshot of the output of the PD signal from MI for 70 kV source

The Figure 4.4.1 is the PD output signal of the test object with the 50 kV applied voltage, and Figure 4.4.2 is the output signal from MI for 50 kV Source voltage.

By giving different applied voltages has observed the pulse movement.

From the MI (Figure 2.2) got this output and can observe the rise time and fall time in this graph.

Observation with one pulse

Duration of the Rise time= 0.00971834-0.0097182 sec

Rise time = 5.14 µsec

Duration of the fall time =0.0098234-0.0098232 sec

Fall time = 5.14 µsec

Amplitude = 1.5 mV

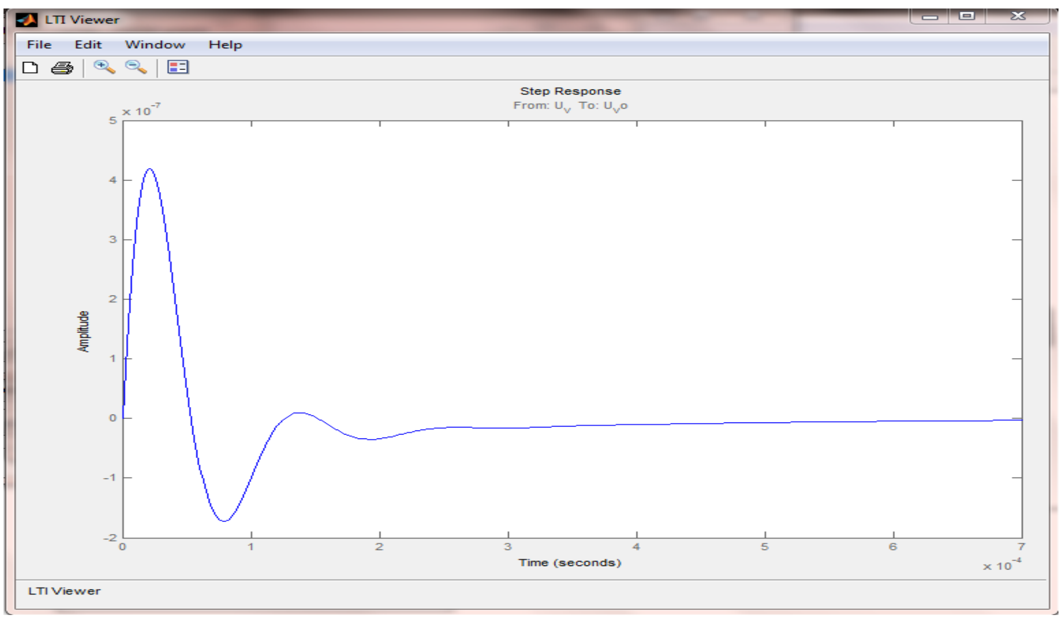

Figure 4.6. Step response of the PD pulse in transformer winding.

The Figure 4.6 shows step response of the PD pulse in LTI viewer. From here can do the study about the rise time fall time of the frequency response.

4.2 PD Pulse in the Transformer winding

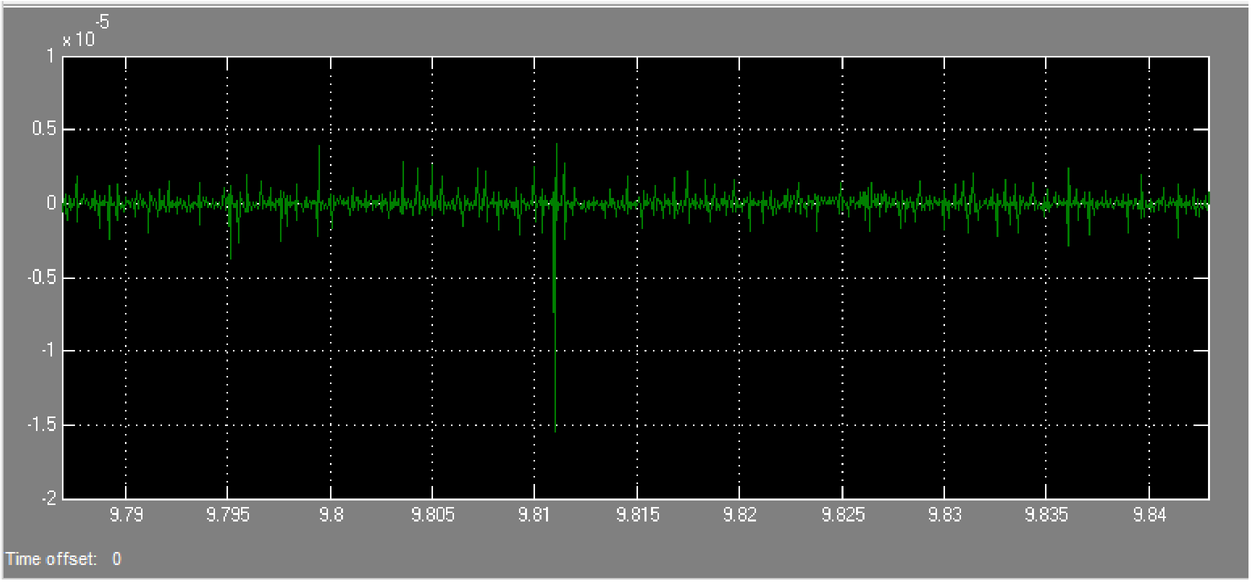

Figure 4.7. PD pulse in transformer winding number 3.

The Figure 4.7 shows the PD pulse of the 3rd winding. Which is near to the Source Voltage.

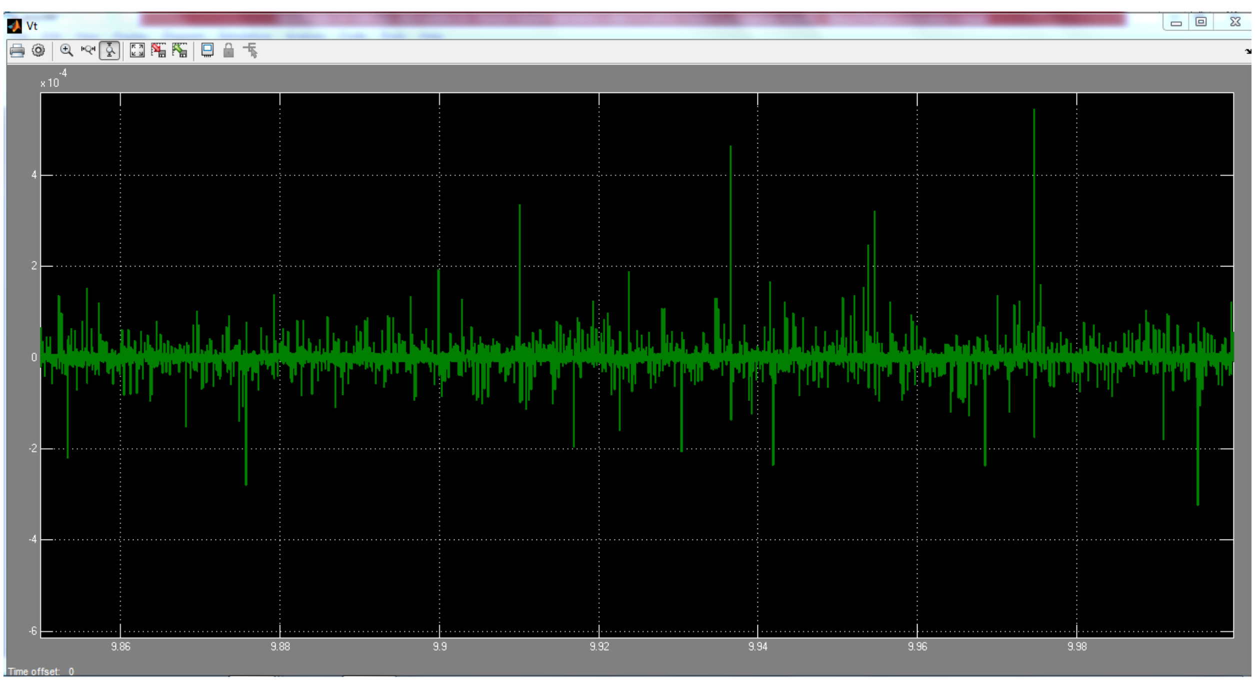

Figure 4.8 PD pulse in transformer winding number 6.

The Figure 4.8 shows the PD pulse of the 6th winding in the transformer. It is almost middle among 10 windings. So while comparing with the Figure 4.7, Figure 4.8 PD pulse movement is quite different. The high peak amplitude moves the right side of the picture.

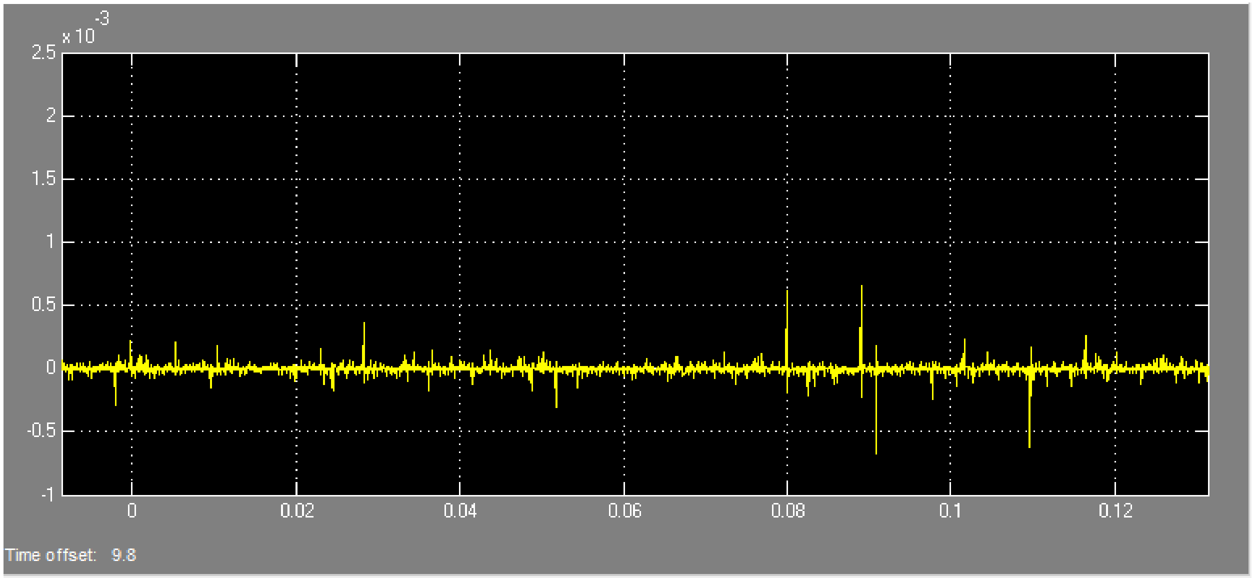

Figure 4.9. PD pulse in transformer winding number 8.

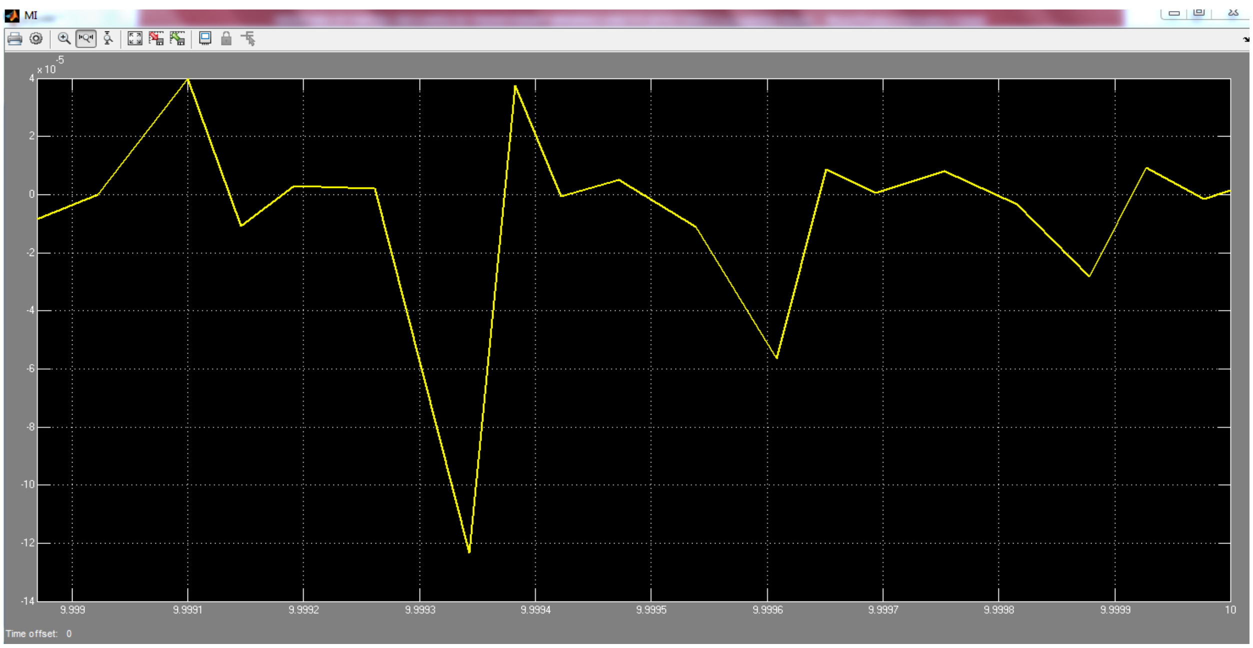

Figure 4.10 Rise times fall time observed PD pulse

As a final point in Figure 4.9 it shows the PD pulse on the 8th winding. Which remains outlying from the source voltage owing to that PD amplitude too stimulated thus far, associated to the other two Figures 4.7 and 4.8 .

Hence can come to the inference that the testing near the supply the magnitude of the signal is high and when it is away from the supply voltage the magnitude will be less. That means with the distance from the source it's getting decreasing. These all are represent the mechanism of the PD pulse, as already discussed in section 4.1. Have taken 20 samples from the output signal and observed the time duration on rise time and fall time.

Table 2: *Rise time and fall time of the PD Pulses with time variant*

Time duration of rise time	Rise time (10¯6)μsec	Time duration of fall time	Fall time (10¯6) μsec	Amplitude (mv)
0-0.000819	- 819	0.00819-0.00739	- 800	- 1.5
0.00739-0.00659	- 800	0.00659-0.07659	- 800	- 1.4
0.07659-0.08459	- 800	0.08459-0.09259	- 800	- 0.9
0.09259-0.010059	- 800	0.010059-.010859	- 800	- 1.3
0.010859-0.011659	- 800	0.011659-0.012459	- 800	- 1.35
0.012459-0.013259	- 800	0.013259-0.014059	- 800	- 1.2
0.014059-0.014859	- 800	0.014859-0.15659	- 800	- 0.743
0.015659-0.016459	- 800	0.015659-.0106459	- 800	- 0.79
0.0106459-.017259	- 800	0.017259-.018059	- 800	- 0.35
0.018059-0.018859	- 800	0.018859-0.019659	- 800	- 0.3
0.019659-0.020459	- 800	0.020459-0.021259	- 800	- 1.5
0.021259-.022059	- 800	0.022059-0.022859	- 800	- 1.5
0.022859-0.023659	- 800	0.023659-0.024459	- 800	- 2.1
0.024459-0.025259	- 800	0.025259-0.026059	- 860	- 2.2
0.026059-.0268859	- 800	.0268859-0.027659	- 800	- 0.987
0.027659-0.028459	- 800	0.028459-0.029259	- 800	- 0.687
0.0257-0.0275	- 800	0.0266-0.0275	- 800	- 0.596
0.0275-0.0296	- 800	0.0286-0.0296	- 800	- 0.45
0.0296-0.0314	- 800	0.0304-0.0314	- 800	- 0.21
0.0314-0.0304	- 800	0.322-0.002	- 800	- 1.5

In the beyond table it’s clearly viewing that the rise time and fall time remain same. Bothe the rise time and fall time are in microseconds, and the amplitude will be in mille volt.

The pulse is characterized by rise time (Tr), decay time (Td), and pulse width (Tw). Pulse rise time (Tr), is the time required to rise from 10% to 90% points of the peak pulse value; pulse decay time (Td), is the time required to decay from 90% to 10% points of the peak pulse value; whereas pulse width (Tw), is the time interval between 50% levels on both sides of the peak pulse value.[9]

Accordingly the Result

Rise time=800 μsec

Fall time =800 μsec

CONCLUSION

Chapter – 05

CONCLUSION

Here to study about the Partial discharge in the transformer void its winding we have developed the simulation program by using MATLAB software. In starting to understand the phenomena of the partial discharge created a void inside the cubic model and calculated the parameters of the equivalent circuit of the PD mearsument and simulated with a variable HV power source and observed the PD pulse .After In simulation created equivalent circuit for the transformer winding and tested the PD magnitude movement .From this we got a conclusion that the PD magnitude near to the source voltage is high and the distance from the voltage source the PD magnitude will decrease. For that among 10 windings we tested 3rd, 6th and 8th windings. Also observed the rise time and fall time of the PD pulse. To observe the PD pulse we have taken 19 samples and calculated their rise time and fall time with the correspond amplitude.

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